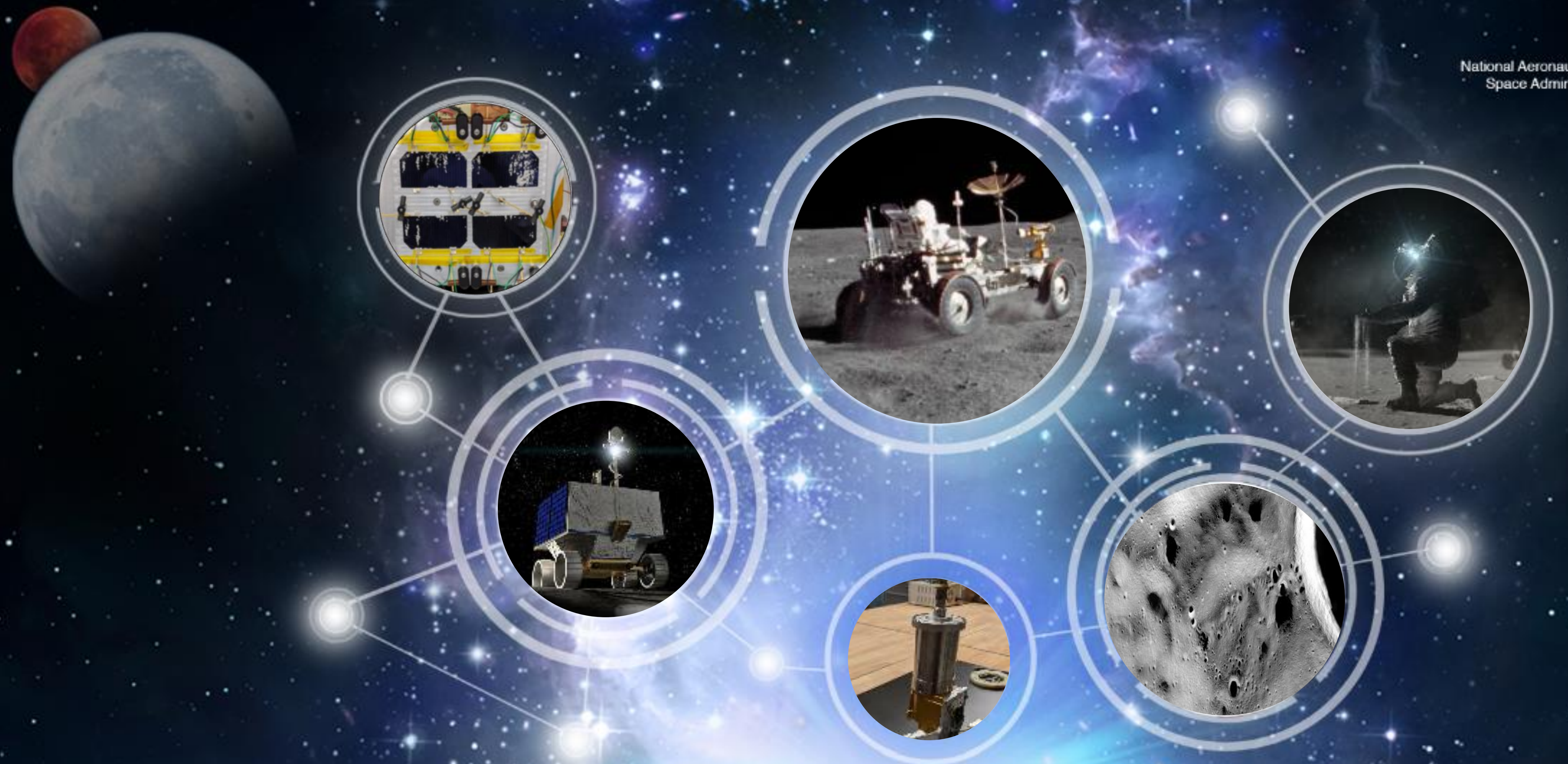

An Overview of Surveying Lunar Dust Influence on Device Efficacy (SLIDE)

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45th Meeting of the Adhesion Society, San Diego, California | February 20-23, 2021

Image Credit: NASA

Lunar Dust Mitigation Issues

- The Problem: Hazards associated with hard, sharp, fine, chemically reactive lunar dust
  - Impact on people:
    - Potential inhalation health hazard
    - Embeds in, abrades soft materials
    - Reduces visibility through optical surfaces by scatter and scratching
  - Impact on habitats, equipment, and mission operations:
    - Reduces performance efficiency of solar arrays and radiators
    - Compromises sealing of critical, gas-tight surfaces
    - Accelerates wear on and increases jamming of moving surfaces
    - Variable with lunar locations and specific dust characteristics

Apollo astronaut glove covered in lunar dust

Apollo missions demonstrated that dust was a limiting factor for lunar surface operation and posed a health concern when it penetrated habitable spaces. Dust mitigation (DM) is required to enable Artemis.

Image Credit: NASA

Apollo Program and Lunar Dust Experience

Apollo 17 Astronauts Gene Cernan and Ronald Evans in the Lunar Module, Challenger, after their third and final EVA, doffing their EMUs

Image Credit: NASA

Lunar Dust Mitigation Needs

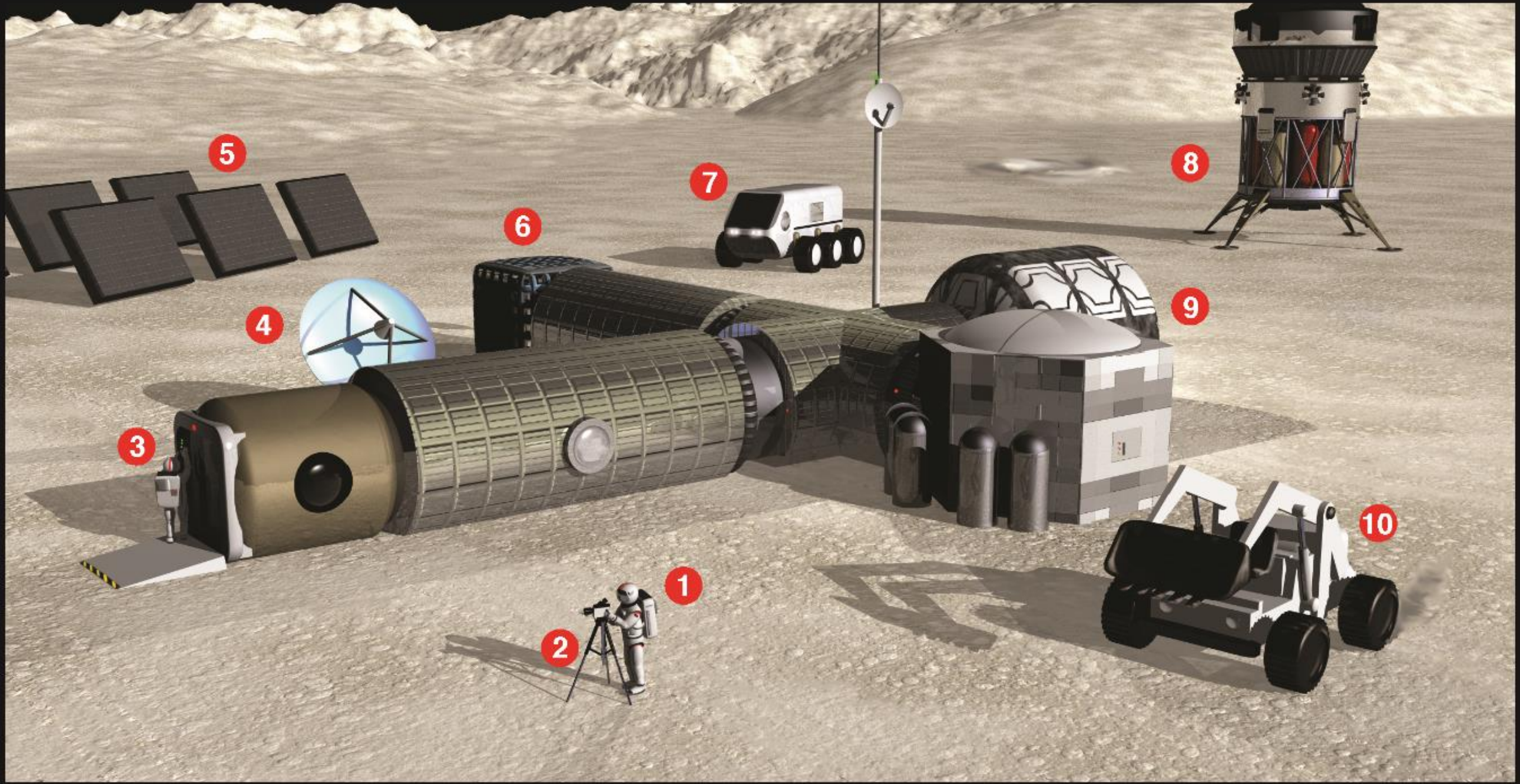
➢ The Need:

- Reduce health hazard associated with incidental exposure
- Improve functioning and increase equipment lifetime
- Expand lunar surface mission options, longer lifetime for deployed systems, minimize risk of lunar system capability loss (i.e., magnitude and duration) and increase system reliability, and create a greater probability of mission success
- DM is needed to support NASA's Plan to Return to the Moon by 2024 and Lunar Sustainability by 2028 (LSII project)

Quantitative Impact: Preliminary studies show adhesion reductions of 80% to 95% for various removal techniques.

Flanagan and Goree, Dust release from surfaces exposed to plasma, Physics of Plasma 13, 123504, 2006. Schwan, J., et al., The charge state of electrostatically transported dust on regolith surfaces, Geophy. Res. Lett., 44, 3059, 2017. Godyak. V,. Ferromagnetic enhanced inductive plasma source. J. Phys. D: Appl. Phys., 46, 283001, 2013. Wang. X et al. https://sservi.nasa.gov/articles/video-dust-charging-and-mobilization/

Key Areas of Dust Mitigation



Lunar Dust Adhesion Mitigation Opportunities and Needs

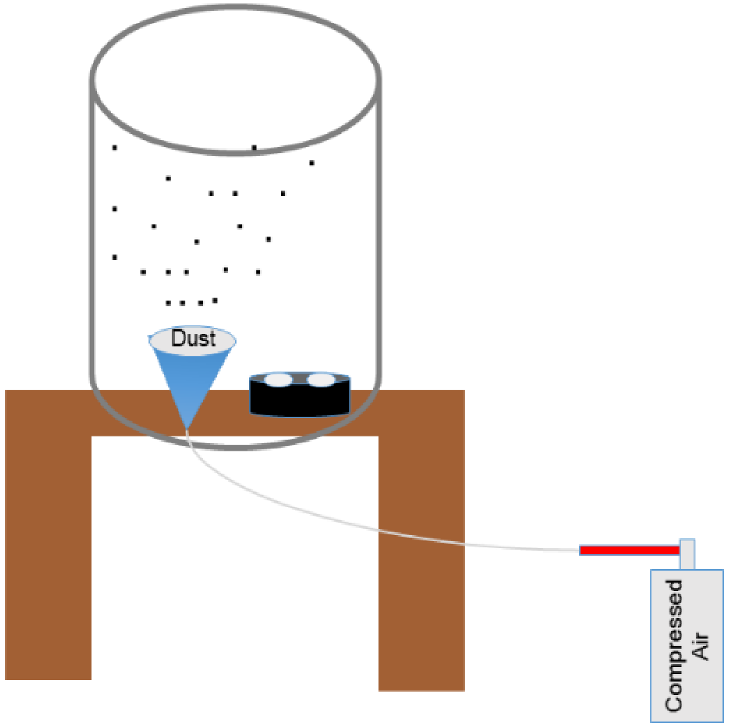
1. **Environment suits** Visors, joints, controls
2. **Sensing / optical equipment** Lenses, sensors, connectors
3. **Airlocks** Door seals, interior surfaces, controls
4. **Communications equipment** Dish surfaces, sensors
5. **Solar arrays** Panel surfaces
6. **Power distribution equipment** Connectors, radiators
7. **Lunar rovers** Gears, bearings, shafts, screens, radiators, instrumentation
8. **Lander / Landing site** Hatches, instrumentation, fueling equipment
9. **Habitat** Joints / seals / interlocks
10. **Excavating equipment** Bearings, controls, gears

Image Credit: NASA

Current Testing Developments

Deposition Chambers

Schematic



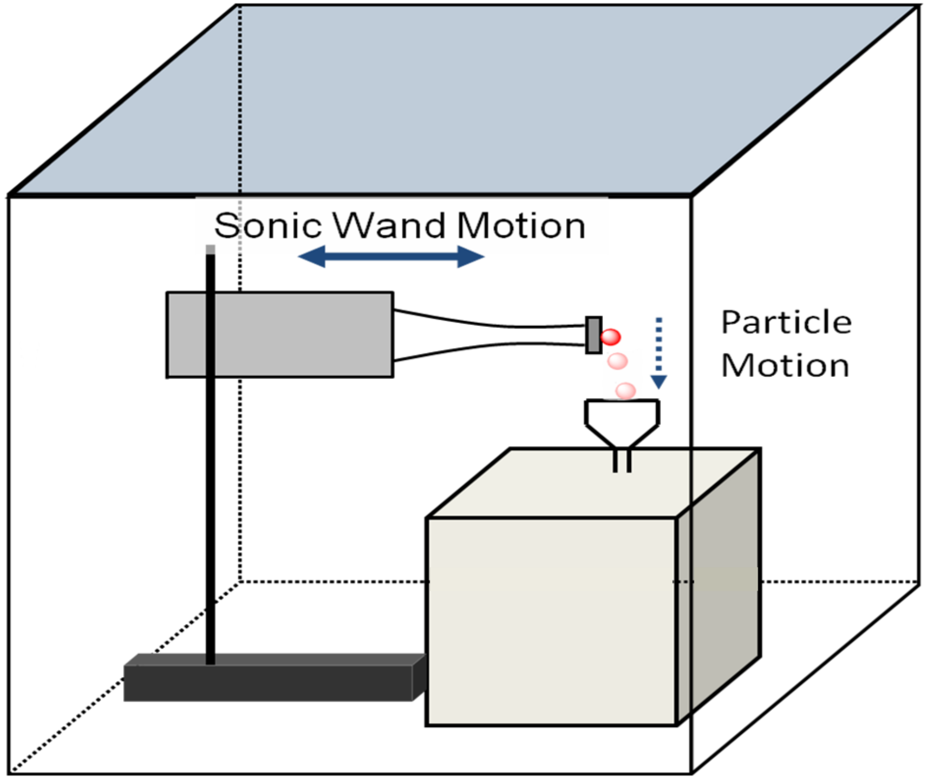
Laboratory Equipment

Image Credit: NASA

Current Testing Developments

Adhesion Test Chamber

Schematic



Laboratory Equipment

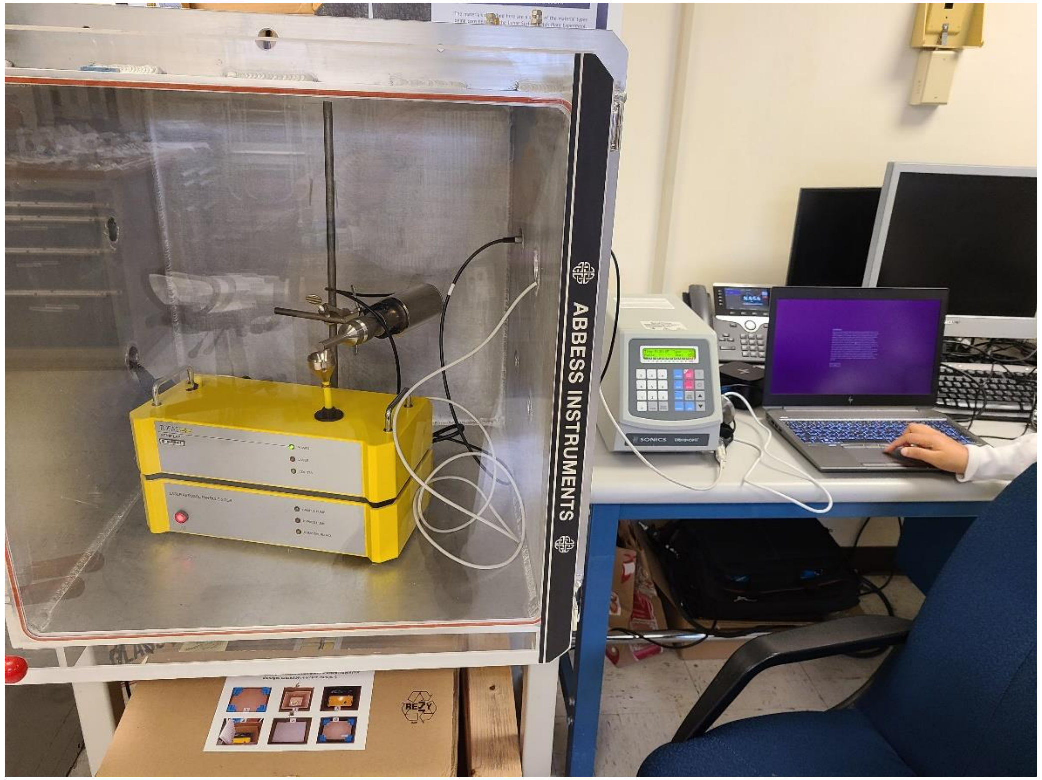


Image Credit: NASA

Current Abrasion Testing Methods

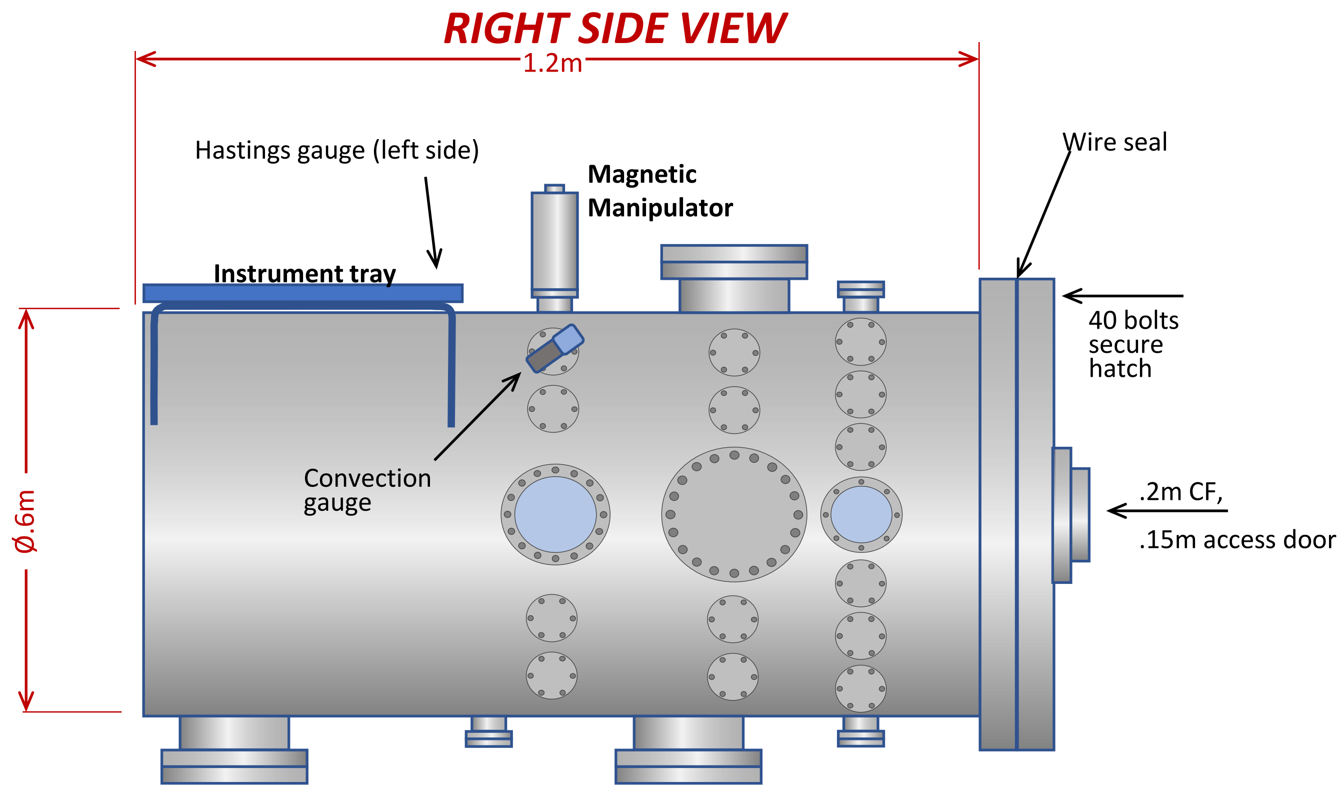
- **Taber Abrasion**
  - **ASTM D1044/C501/D4060/F1978**
- **High Stress Abrasion Testing**
  - **ASTM B611**
- **Falling Sand Abrasion**
  - **ASTM D968**

- RCA Abrasion
  - ASTM F2357
- Pin Abrasion
  - ASTM G132
- Rubber Wheel Abrasion
  - ASTM G65

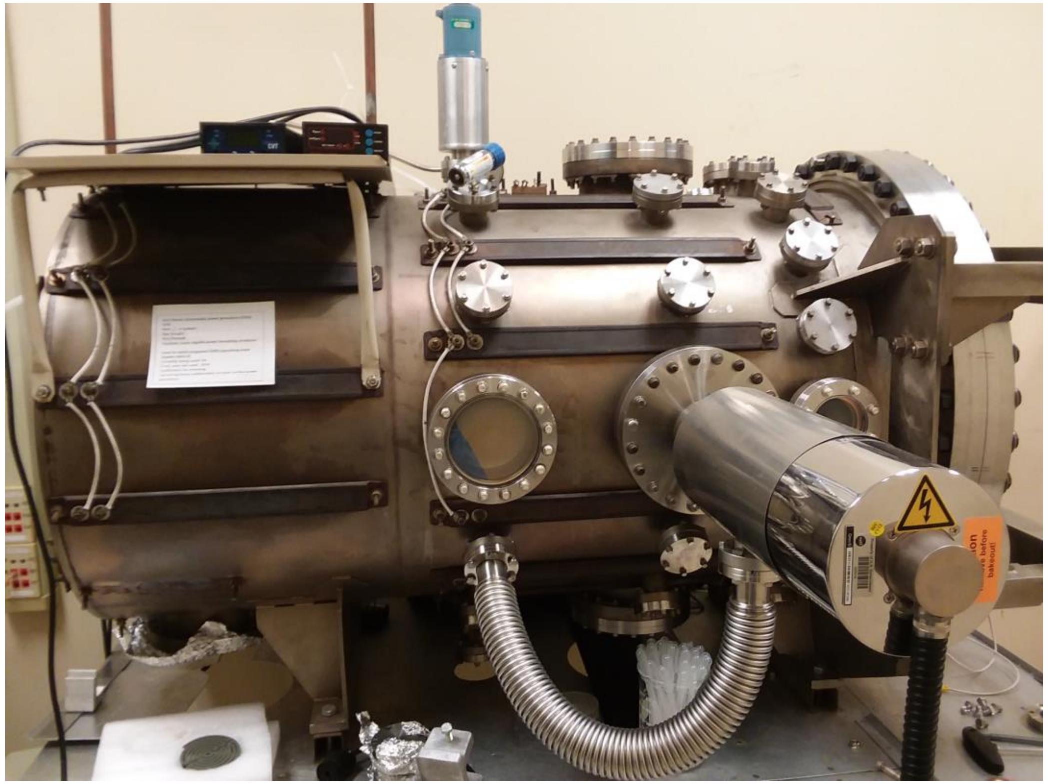
Image Credit: NASA

Surveying Lunar Dust Influence on Device Efficacy (SLIDE)

Schematic



Instrument Pre-Assembly

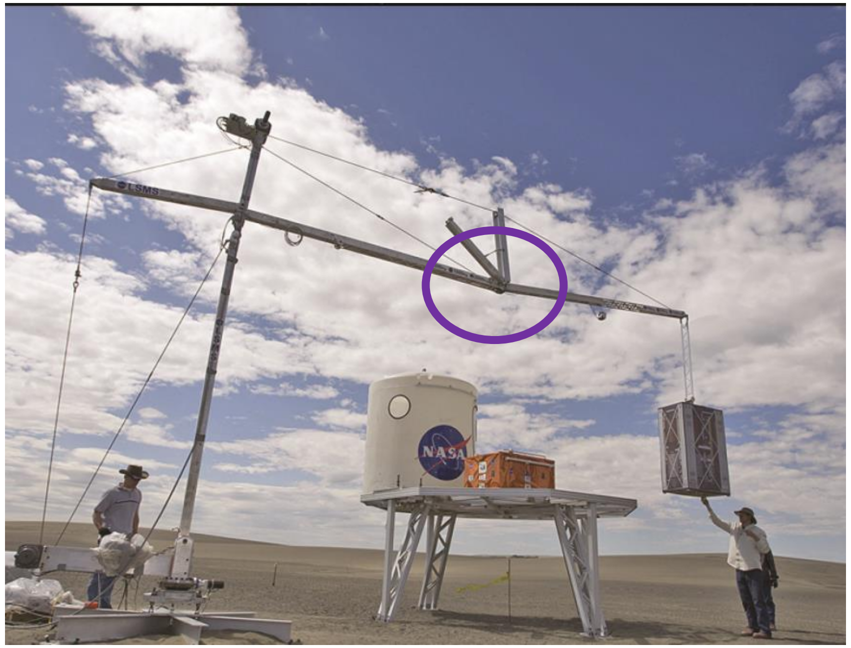


Units are in Meters

Image Credit: NASA

SLIDE Testing Mechanism

Lunar Surface Manipulation System (LSMS)



1. Supporting Bracket
2. Testing Coupons
3. Active Disk
4. Motor
5. Lunar Simulant
6. Dust Shaker
7. Container (Cross Section View)

Schematic of SLIDE Testing Mechanism

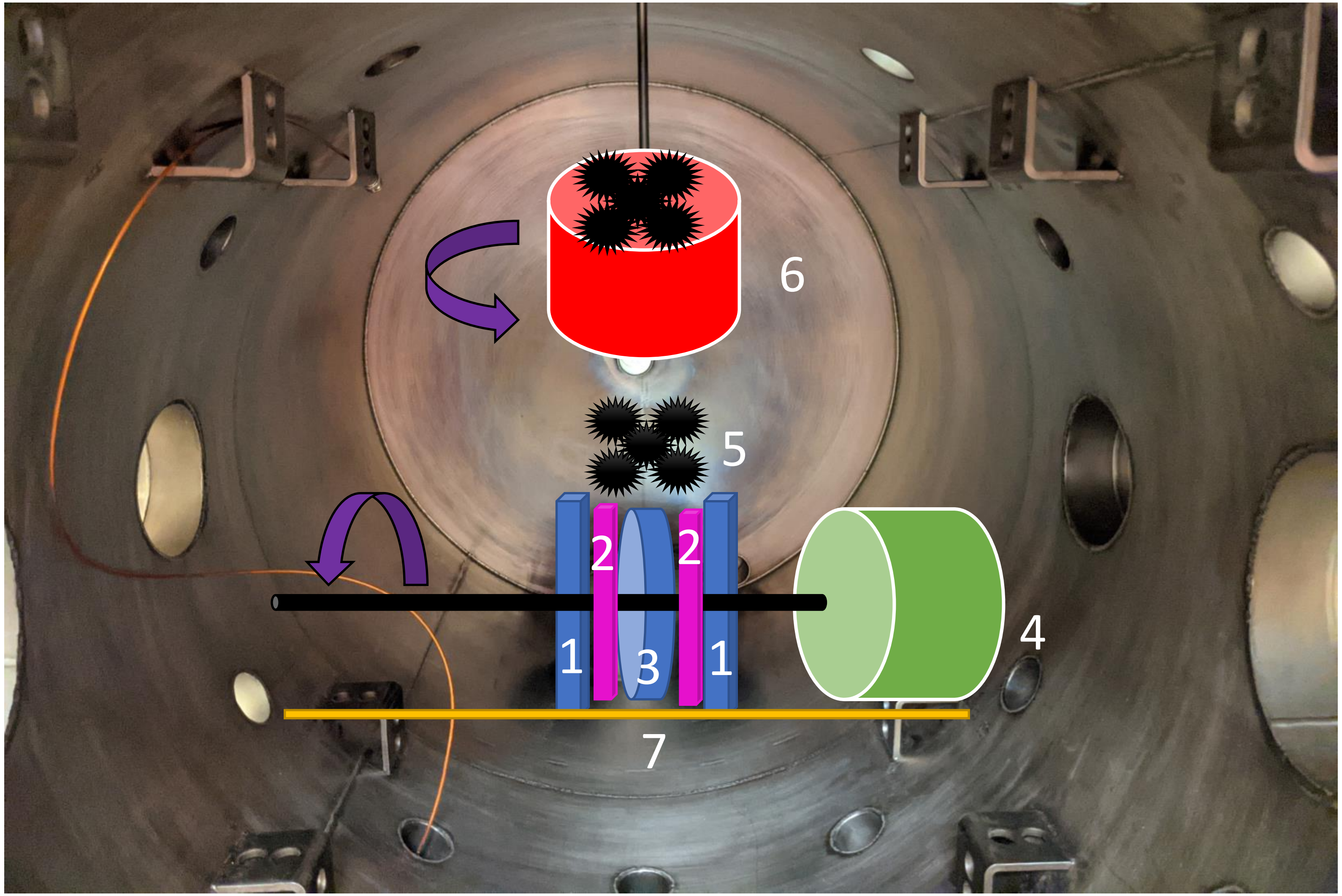


Image Credit: NASA. Objects not to Scale

Dust Shaker

Image Credit: NASA/NIA

Testing Area

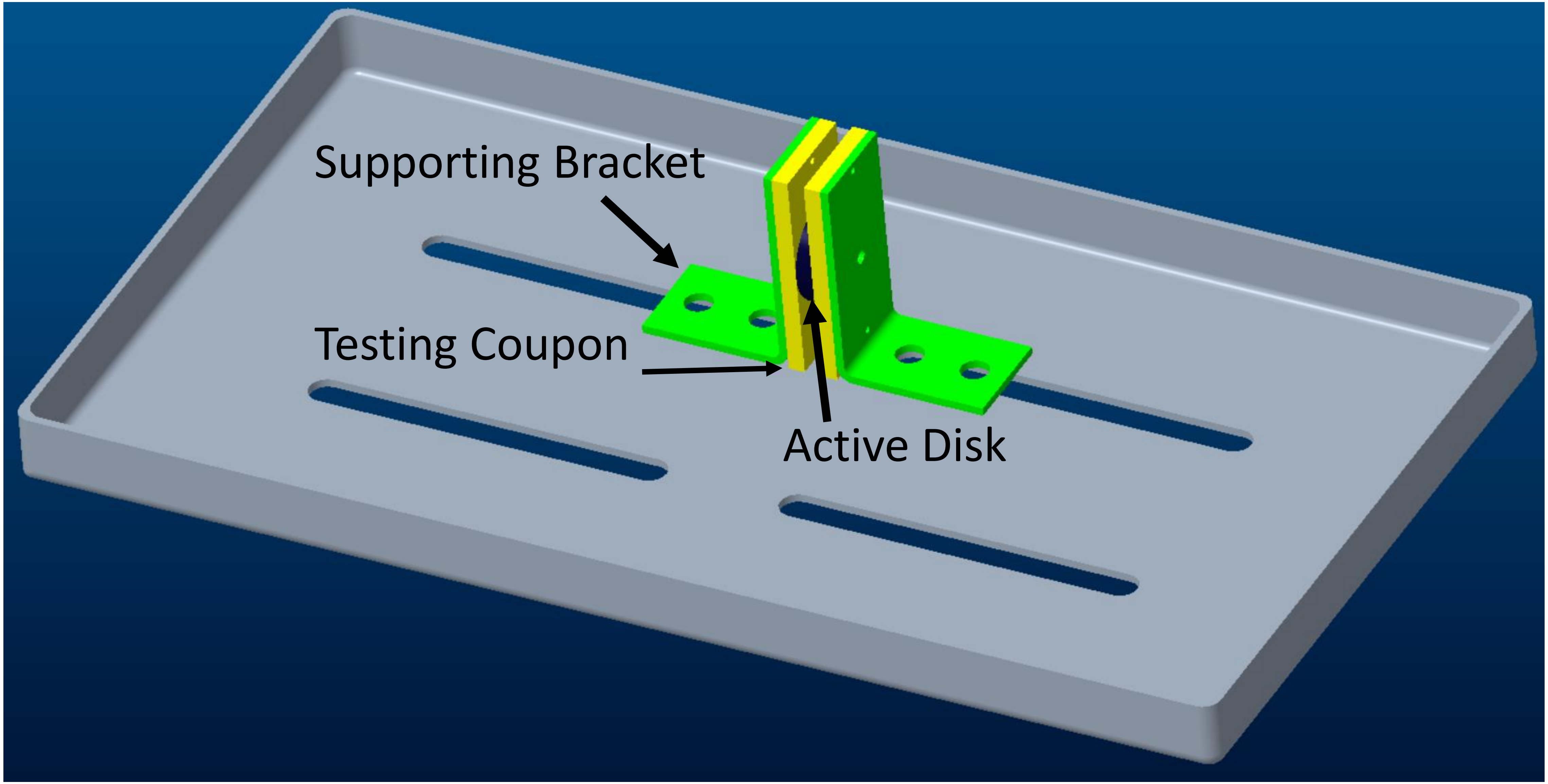
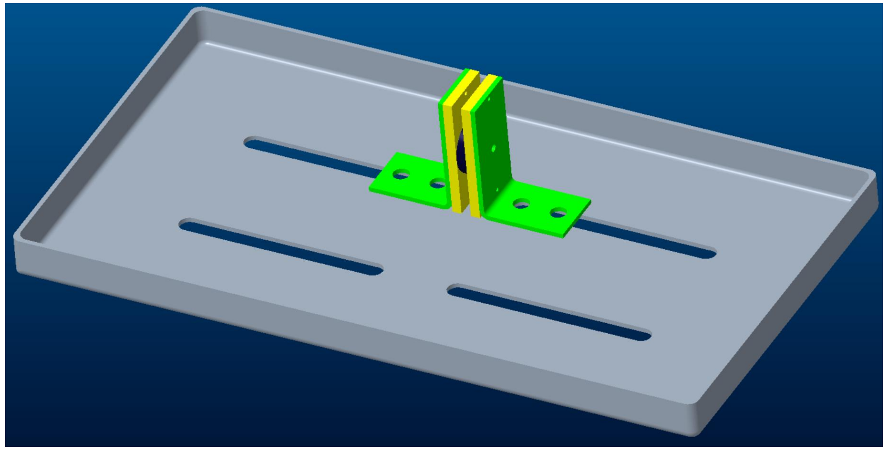


Image Credit: NASA/NIA

Specifications



	Material Coupon		Active Disk	
Sizes	Standard	Max	Standard	Max
Width (mm)	37	75	25 Diameter	25 Diameter
Height (mm)	75	125		
Thickness (mm)	6	12	12	12
Substrate Candidates	Al 6061		Ti-6Al-4V	
	Other Candidates: SS 304 & Al 2024			
Coating Candidates	Teflon for Comparison TBD after Preliminary Taber Testing			

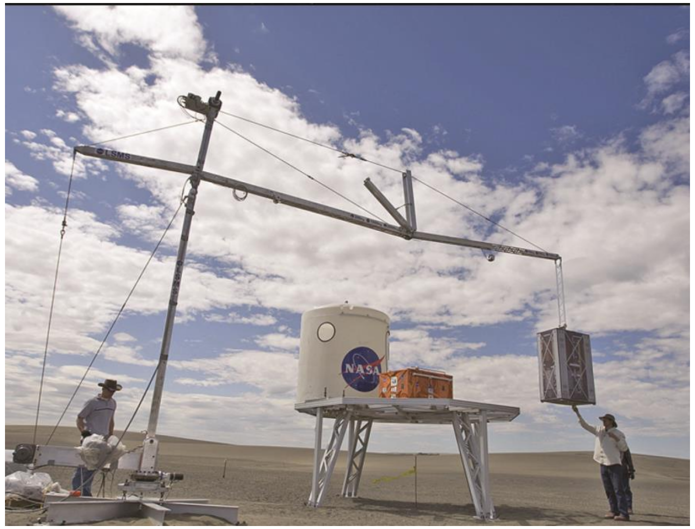
Image Credit: NASA/NIA

Experimental Parameter Variables

- Motor Performance Over Time
  - Evaluation of motor behavior through changes in torque, rotational speed, etc.
- Energy-dispersive X-ray Spectroscopy and/or Particle Counter
  - Quantification of the magnitude of material degradation by determining the amount of particles that are not a component of lunar regolith.
- Microscopy for Surface Profiling
  - Electron Micrographs and Laser Confocal Imaging to assess overall wear induced by lunar regolith.

Current Equipment Limitations

- **Flow Rate of Simulant**
  - Limitations on the amount of simulant that can be deposited over time
  - Useful for Mars related work



- **Contamination During Experimentation**
  - Abrasiveness of metals due to low hardness
  - Current material candidates are hardened steel and titanium
  - Quantify data through Energy Dispersion Spectroscopy

- **Outgassing**
  - Compacting dust can result in mechanism jamming
  - Discussions made with other NASA Centers (Glenn Research Center, Jet Propulsion Laboratory, Marshall Space Flight Center) to mitigate risk
  - Studying other dirty vacuum chambers built for lunar regolith research (Southwest Research Institute & Korea Institute of Civil Engineering and Building Technology)

Image Credit: NASA

Future Work

- Initial testing and trial runs planned under atmosphere before proceeding with vacuum up to 10^{-4} torr
- Consider new chamber improvements
- Consider new quantifiable measurements for abrasive/adhesion testing
- Implement knowledge gained for new testing benchmarks
- Combine efforts in other Lunar Occupation Dust Surface Separation Technologies (Lo-DuSST) tasks in active mitigation for vacuum environment testing

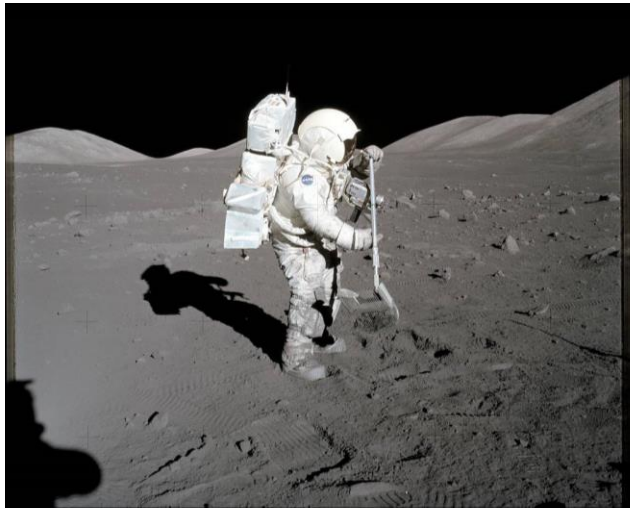


Image Credit: NASA

Summary

- The damaging properties of lunar regolith require a multi-faceted approach to mitigate adhesion and overall wear for Artemis.
- The Lo-DuSST project plans to incorporate both passive and active technologies to reduce lunar-regolith related wear and adhesion.
- SLIDE will be introducing a new testing capability under a vacuum environment to test passive adhesion mitigation technologies.

Acknowledgements

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